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Compete or cooperate: Intensity, dynamics, and optimal strategies

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Abstract: This research explores rival firms' optimal strategies when engaging in market competition. We assume that customer demand is subject to customer sensitivity to the competitors' price and service levels. First, we develop coopetition models under a symmetric case where there is identical service-investment efficiency between two firms. We then extend our analysis to an asymmetric case in which the two firms have different service-investment efficiencies. Our results show that the optimal strategic decisions regarding whether to compete or cooperate and how to cooperate depend on the intensity of the market competition in which the firms are engaged. The results also indicate that coopetition changes the dynamics of the competition and cooperation between the rival firms. More specifically, on the one hand, coopetition eases competition intensity in the cooperating area, for example, price or service; on the other hand, it increases competition intensity in the non-cooperating area. Decision frameworks are proposed that enable firms to make optimal strategic decisions on coopetition under various market conditions.

Keywords: Coopetition; competition intensity; coopetition dynamics; optimal strategy.

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1 Introduction

Despite increasing levels of service competition in many industries, there has also been a paradigm shift from competition to *coopetition*. While some companies have set up their own service strategies to compete with rivals, others have decided to cooperate with rival firms to improve their competitive advantages. For instance, among online retailers, some have invested in distribution and logistics operations to provide their own delivery services, whereas others have chosen delivery services provided by other firms, such as Amazon, while still competing with each other for customer demand (Chen et al. 2016). Hisense and Haier, despite being main market rivals in the household appliance sector in China for many years, have recently cooperated to establish after-sales service stores that serve customers of both firms in order to reduce their after-sales service costs. In the iron ore industry, three mining giants—Rio Tinto, Vale, and BHP Billiton—often cooperate together to influence the iron ore price of the market. In the airline industry, many airlines have formed strategic alliances, agreeing to cooperate at a substantial level and making collaborative decisions, for example, on service provision, resource allocation, and pricing (Chen and Hao 2013). Although competing firms engage in cooperation at different levels, this kind of strategic behavior is becoming more popular across a variety of industries, such as the mobile communications, automobile, and high-tech sectors.

This strategic behavior is known as *coopetition*, a phenomenon defined as the simultaneous pursuit of cooperation and competition by firms (Brandenburger and Nalebuff 1996; Dowling et al. 1996; Bengtsson and Kock 2000; Gnyawali et al. 2006; Chen 2008). Since the seminal work by d’Aspremont and Jacquemin (1988) on cooperative and non-cooperative research and development (R&D), the concept has attracted growing interest among practitioners and academics. The existing literature argues that coopetition is the most advantageous relationship between competitors (Bengtsson and Kock 2000) and firms can achieve superior performance and gain economic benefits by deriving valuable resources from their coopetitive relationships and from strengthening their competitive capabilities (Lado et al. 1997; Gnyawali and Madhavan 2001; Gnyawali et al. 2006; Gnyawali and Park 2009). In the retail setting, legitimate competitive behavior is rewarded by support from other actors in the market, with clear domains for cooperation and competition (Varman and Costa 2009).

While there are some obvious benefits to cooperating on service provision, it is not clear how such cooperation affects the nature of competition, as these firms are competing for consumer demand at the

same time. Coopetition can also be a risky relationship that is detrimental to cooperation effectiveness and can result in failure (Park and Russo 1996; Kim and Parkhe 2009; Ritala 2012). The success of a coopetition strategy is not only significantly influenced by the relationship between the coopetition entities and firm-specific factors, but also by the embedded economic and market context (Ritala 2012). This may explain why coopetition strategies are often adopted in highly dynamic and competitive markets. Furthermore, in the high-tech industry, which is characterized by short product life cycles, rapid technical advancement, high R&D expenses, and fierce competition, these pressures, as well as the need for technology standards, drive many technology firms to collaborate with their fiercest competitors. However, the simultaneous pursuit of competition and cooperation may also change the nature of competition (or cooperation) and the dynamics of coopetition between firms. The changing environment and firms' enhanced capabilities and competitiveness achieved through coopetition may also force them to reevaluate their coopetition strategies.

Although coopetition has become a heated topic, both in practice and in research, there are some important questions that still demand clear answers. Observations from the academic literature and real-world examples motivated us to explore the important issues of coopetition and contribute to the progress of coopetition research. The focus of our study is, therefore, on a firm's optimal coopetition strategy and on the market environments in which such a strategy is successful. In particular, we investigate the following questions:

- Does coopetition on service provisioning generate superior financial performance?
- What is the best strategy for a firm engaging in coopetition?
- How does market competition affect a firm's strategic decision around coopetition, and conversely, how does coopetition impact the nature of market competition?

The purpose of this study is to investigate the dynamics of coopetition and the effects of coopetition strategies on firms' operational decisions and financial performance. To this end, we consider two firms at the same level in the value chain competing with each other by selling substitutable products to end customers in a market. Due to the dynamic and competitive market environment, firms must compete with more sophisticated strategies, rather than by simply lowering prices. Some of the non-price factors, such as service, have become more important in affecting a consumer's purchase decision (Iyer 1998; Tsay and Agrawal 2000; Bernstein and Federgruen 2004). The service here represents all forms of demand-promotion effort, which include sales promotion; customer service before and after the sale,

such as maintenance and warranty repair agreements (Cohen and Whang 1997; Xia and Gilbert 2007); financial services, such as loans and insurance in the automobile industry; and the overall quality of the shopping experience, such as delivery service, among others. Thus, in addition to price, service is a critical element in a firm's operational management and marketing strategy (Xiao and Yang 2008). Therefore, firms have to make a strategic choice not only between competition and coopetition, but also regarding the business areas that they choose for cooperation. It can be a single coopetition area, such as delivery service for online retailers or aftersales service for household appliances manufacturers, or multiple areas, as applied in the airline industry.

As price and service are the most important factors that influence customer purchasing decisions and most firms invest significant resources to ensure optimal strategic and operational decisions on price and service, we therefore take price and service as the entry points to study coopetition. We specify two market scenarios. Under these two scenarios, in addition to the influence of the focal firm's price and service, customer demand is also affected by its rival firm's price and service. Under each specified scenario, first, we use non-cooperative games to develop the competition models in which firms only compete with each other to maximize their own profits. Second, we use the cooperative games to develop coopetition models in which the two rival firms make joint decisions on prices and/or service levels in order to seek a win-win scenario in which firms increase profits between them. Since the main incentive for firms to engage in coopetition is to increase their individual profit, we also introduce a cost-sharing contract through which firms can share the cooperation cost and ensure that both firms are better off when there is an increase in total profit from coopetition. The power of cooperative game theory is in its ability to analyze value creation and capture in markets, especially in settings where firms' dealings do not follow some predefined process (Brandenburger and Stuart 1996). Through studying the firms' equilibrium decisions and a comparison of consequent financial performance, we examine the optimal strategies under different scenarios in an attempt to understand how the success of a coopetition strategy is affected by the characteristics of the market competition and how the nature of competition evolves under different coopetition strategies.

The main contribution of this study to the extant literature on coopetition is twofold. First, this research uses non-cooperative and cooperative games to develop the competition and coopetition models and analyze how value is created and captured in the market. We examine the impact of the strategic choices among competition, service coopetition, and service and price coopetition on firms'

operational decisions and performance. By modeling the intensity of the competition in the analytical models and different levels of coopetition (e.g., single- and dual-element coopetition), the systematic analyses provide insights into the dynamic relationship between competition and coopetition, as well as between the two competing elements in the dual-element coopetition. Such an exploration of the interactions between competition and cooperation provides some novel predictions around firms' strategic behaviors that have not been observed in existing theoretical perspectives (Peng et al. 2012; Dahl 2014; Dorn et al. 2016). Second, our research provides some interesting insights that have not been captured in the previous literature. Through the examination of the coopetition effect on firms' total profits, we are able to identify the decision areas where the associated competition or coopetition strategies can have a positive economic impact. A further coordination mechanism, namely, a cooperation cost-sharing contract, is also proposed to enable coopetition strategies to deliver better financial performance. Based on the findings, a two-dimensional decision framework (price and service) is developed to provide strategic guidance for firm decisions on coopetition strategies. Practically, it is beneficial for firms to make optimal strategic decisions that enhance their competitive capabilities in challenging market environments.

The remainder of the paper is organized as follows. The relevant literature is reviewed in Section 2. In Section 3, the model formulation and assumptions are presented. Section 4 examines the impact of coopetition on firms' operational decision making and economic performance in the symmetric case in which the two firms have an identical level of service-investment efficiency. In Section 5, we extend our analysis to an asymmetric case, in which the two firms have different levels of service-investment efficiency. We derive the optimal pricing and service level decisions and discuss the effects of service-investment efficiency on the firm's strategic and operational decisions in different market scenarios. Finally, in Section 6, we draw conclusions and highlight possible directions for future work.

2 Literature review

Brandenburger and Nalebuff (1996) provide a broad definition that views coopetition as a value net consisting of a firm's suppliers, customers, competitors, and complementors. Their interdependence involves both competitive and collaborative elements, with rivalry as well as collaborative mechanisms, in the course of profit maximization for the firms. Bengtsson and Kock (2000) give a narrow definition

that regards coopetition as a dyadic relationship involving firms' simultaneous engagement in competition and cooperation. Although there are various definitions and conceptualizations of coopetition, along with their respective levels, these all closely relate to either broad or narrow definitions, which are branded by Bengtsson and Raza-Ullah (2016) as the actor or the activity schools of thought, respectively. The underlying concept of the actor school of thought is the “value-net,” in which actors cooperate to create a larger cake and then compete to divide it up; the activity school of thought concentrates on simultaneous competitive and cooperative relationships, rather than a network context (Bengtsson and Raza-Ullah 2016).

In view of the growing interest among management researchers in coopetition in the past two decades, some comprehensive systematic reviews (Stein 2010; Bouncken et al. 2015; Bengtsson and Raza-Ullah 2016; Dorn et al. 2016) have been conducted to foster a better understanding of the coopetition phenomenon, along with suggestions for strengthening this research area in the future. Among them, Bengtsson and Raza-Ullah (2016) integrate key critical themes into a Driver, Process, and Outcomes framework in an attempt to provide a richer and more complete perspective of the coopetition phenomenon. Dorn et al. (2016), in their systematic review of coopetition contributions in the management literature, analyze and synthesize coopetition research and highlight five multilevel areas for future investigation: (1) nature of the relationship, (2) governance and management, (3) output of the relationship, (4) actor characteristics, and (5) environmental characteristics. Readers may refer to these recent review works for more information about coopetition. In order to refine the research questions and highlight our contributions, the review presented below mainly focuses on the following two aspects: the intensity of competition and cooperation; and the dynamics of coopetition.

2.1 Price and service competition

As setting price and service levels are important operational management decisions, many studies have considered price and service dual-dimension competition in the investigation of various business problems. Tsay and Agrawal (2000) study a distribution system in which two retailers purchase product from a common manufacturer and use service as well as retail price to compete directly for end customers. They show that the relative intensity of competition with respect to price and service dimensions plays a key role. Bernstein and Federgruen (2004) develop a stochastic general equilibrium inventory model considering three competition scenarios and including service level and price. As an extension, Bernstein and Federgruen (2007) later develop a decentralized supply chain, with long-term

competition between independent retailers facing random demands while buying from a common supplier, and study a coordination problem under price and service competition. They compare the coordination mechanisms when retailers compete only in terms of their prices, and when they engage in simultaneous price and service competition. Dumrongsiri et al. (2008) study the price-service competition between the two channels of a manufacturer (direct channel and retail channel) and find that an increase in the retailer's service quality may increase the manufacturer's profit, while a larger range of customer service sensitivity may benefit both parties. Xiao and Yang (2008) develop a price-service competition model of two supply chains with one risk-neutral supplier and one risk-averse retailer. They find that the impact of the rival's risk sensitivity on the retailer's decision depends on price-service competition intensity. Lu et al. (2011) investigate a supply chain with two manufacturers and a common retailer. Both service and price competition exist between the two products, because each manufacturer provides services directly to customers and the retailer sells competing products to end consumers. Wu (2012) examines price and service competition problems in a remanufactured product supply chain and finds that fierce price competition is more profitable to the remanufacturer, leading to a higher service level. The above research only incorporates the price-service competition in the investigation of different operational decisions, but does not consider the probability that the firms can cooperate on the competing elements. Very recently, Jena and Sarmah (2016) examine price and service competition under uncertain demand conditions in a remanufacturing system context. Although the effects of price and service competition are analyzed, they do not examine the effect of the intensity of competition or whether the level of cooperation affects firms' strategic decisions on cooperation.

2.2 Competition intensity and cooperation level

As discussed, the market competition of a focal firm's industry is often one of the main reasons for its decision to engage in a cooperation strategy. In fact, the competition intensity within the industry has an impact on the benefits of a cooperation strategy. In an empirical study of a cross-industry survey of 209 Finnish firms on the effects of cooperation strategy on firms' innovation and market performance, Ritala (2012) found that the success of the cooperation strategy is affected by market uncertainty, network externalities, and competitive intensity in many different ways. In highly competitive market environments, where there are a number of rival firms offering substitutive products (Dussauge et al. 2000), or in a less competitive environment where there is only a limited number of competitors offering similar products (Peng and Bourne 2009), cooperation can be an effective strategy. According to Oxley

et al. (2009), on the one hand, cooperation with competitors will make the involved businesses more profitable by moderating the intensity of competition in the industry; on the other hand, cooperation will also improve business performance, because of the increased competitiveness among the partnering firms compared with other firms. The argument put forward by Oxley et al. (2009) partially explains how firms can benefit from coopetition in conditions of either high or low competition intensity. A coopetition strategy is important to soften the intense market competition between rival firms or to enhance the competitiveness of the partnering firms when fighting against other rivals in a tight competition.

Despite its importance to firms' strategic decisions on engagement and the success of the strategy, there are general methodological concerns when measuring competition and cooperation intensity in the coopetition research. Among such studies, Luo et al. (2016) pointed out that not incorporating competition intensity in their study of coopetition in low carbon manufacturing was a research limitation. They called for future research that accounted for the intensity of coopetition in the modeling when examining the impact of coopetition strategy on firm decisions and performance. When discussing future research avenues for coopetition research, Bengtsson and Raza-Ullah (2016) also called for the development of new scales for coopetition that could measure the intensity of competition and cooperation, as well as the similarity in their levels.

2.3 Dynamics of coopetition

One distinguishing feature of coopetition is that it is a relationship that contains both competition and cooperation elements simultaneously (Brandenburger and Nalebuff 1996; Bengtsson and Kock 2000). The simultaneous pursuit of competition and cooperation can cause tension between activities and counterparts due to rising internal disagreement (Bengtsson and Kock 2000). Competition emphasizes individual benefits, a zero-sum game, and opportunistic behavior, whereas cooperation promotes common benefits, collective interests, and goodwill (Khanna et al. 1998; Das and Teng 2000). Raza-Ullah et al. (2014) suggest that competition and cooperation are paradoxical forces leading to ambivalent emotions within organizations. It is inevitable that there are tensions inherent in coopetition, due to the conflicting logic behind competition and cooperation (Das and Teng 2000; Bello et al. 2010; Dorn et al. 2016). As a result, the actors involved may experience ambivalent emotions and tensions that stem from coopetition, eventually putting the relationship between the two firms in jeopardy (Gynawali and Park 2011).

Many researchers argue that there is a balanced relationship that requires an optimal combination of competitive and cooperative forces (Bengtsson and Kock 2000; Das and Teng 2000; Quintana-García and Benavides-Velasco 2004; Chen 2008; Cassiman et al. 2009; Peng and Bourne 2009; Dorn et al. 2016). Das and Teng (2000) point out that the stability of a strategic alliance relies on a balance between competition and cooperation. Luo (2004) suggests that coopetition can be closely interrelated with the paradox-solving yin–yang philosophy. He argues that such philosophy naturally fosters coopetition. Similarly, Chen (2008) reconceptualizes coopetitive relationships through an integration of the paradox perspective and the Chinese “middle way” philosophy, and suggests that the two opposite forces may be interdependent in nature and thus together form a totality. Peng and Bourne (2009) argue that it is easier to balance competition and cooperation if there are complementary, but distinctly different sets of resources between the two firms, as well as at the network level, if there are compatible but different network structures. Park et al. (2014) develop the concept of “balance” in coopetition and examine the effect of the balance between competition and cooperation on firms’ innovation performance. In their empirical study of the semiconductor industry, they report that an optimal coopetition balance generates a positive impact on innovation performance. Nevertheless, as Dorn et al. (2016) point out in their review of coopetition, although the existing literature encourages exploration of the balance between competitive and cooperative forces, the challenge is to answer these two questions: what is the optimal balance and how can it be achieved?

Adding to the complexity of the problem, the coopetitive relationship between firms is dynamic, and it may become balanced or imbalanced and change over time (Peng et al. 2012; Dahl 2014; Park et al. 2014; Dorn et al. 2016). Dahl (2014) shows that the interplay of competitive and cooperative elements of the relationship creates the coopetition dynamics. Coopetition is regarded by many researchers to have the potential to affect the competitive dynamics within an industry (Gnyawali and Madhavan 2001; Bengtsson et al. 2010; Ritala 2012). For instance, Niu et al. (2015) find that the partnership between the Original Equipment Manufacturer (OEM) and its competitive Original Design Manufacturer (ODM) mitigates the competition between them in the consumer market. Peng et al. (2012) argue that one firm’s market power could be relatively strengthened through cooperation, and as a result, increase the intensity of competition. Furthermore, firm behavior might shift from cooperative to somewhat competitive in a multilateral alliance where others reduce their input into the relationships (Ritala and Tidström 2014). It is even more challenging to maintain the dynamic balance between competition and cooperation if

external motives and factors are required to establish such a balance.

From a methodology perspective, different approaches have been applied to study coopetition. Despite the call for game theory methods by Brandenburger and Nalebuff (1996) in their seminal work on coopetition, the majority of coopetition research follows the resource-based view (Lado et al. 1997; Quintana-García and Benavides-Velasco 2004; Ritala 2012) or a network approach (Gnyawali and Madhavan 2001; Peng and Bourne 2009; Wilhelm 2011) using conceptual or empirical investigation. Only a few studies (Gurnani et al. 2007; Bakshi and Kleindorfer 2009; Carfi and Schiliro et al. 2012; Luo et al. 2016) have applied game theory to coopetitive decision problems. As acknowledged by Brandenburger and Nalebuff (1996), there is significant potential benefit in investigating how game theory can be used to explore coopetition in complicated and realistic situations, especially the relationship between the incentives and the levels of competition, cooperation, and coopetition in inter-firm relationships. Most relevant to this study is the biform game reviewed by Cachon and Netessine (2006). The similarity is that both non-cooperative and cooperative games are included. The difference is that the biform game is usually a two-stage game in which the first stage is the non-cooperative game and the second is the cooperative game; moreover, there is usually no specific outcome of the cooperative sub-game. However, in our coopetition model, the non-cooperative game is to maximize individual profit, while the cooperative game is to maximize total profits of both firms. In addition, the decision making in our model is simultaneous. This simultaneous game is a standard way to model coopetition and has been used in many representative studies in the literature. For instance, Tsay and Agrawal (2000) analyze the dynamics of retail competition under two scenarios. The first one is that the two non-cooperating retailers are in a competitive environment, in which they make their own price and service level decisions simultaneously to maximize their own profit. The other scenario considers cooperating retailers, in which they make decisions simultaneously and cooperate to maximize their total profit. Zhang and Frazier (2011) consider three competing firms selling substitutable goods in the same market, where two of them form an alliance in the coopetition game. In the study, firms make their pricing policies at the same time. Recently, Jena and Sarmah (2016) study price and service coopetition among two remanufacturers considering uncertain demand and condition of the acquired items. They consider four different configurations of remanufacturing, in which the difference between the global system and integrated system depends on whether the two remanufacturing firms cooperate or not. When the firms cooperate, the total profit is maximized. In addition, the remanufacturing firms choose their

policies simultaneously among the four different configurations. In our paper, we also follow this theoretical approach.

In summary, despite increasing interest among practitioners and academics and a growing number of studies on coopetition in various areas of management, as far as we know, there is limited research using a game-theory approach to investigate service and price coopetition and the impact of the strategic choice between competition or service and price coopetition on firm performance. Our research aims to fill this gap in the literature and explore this approach by systematically looking at how competition intensity affects firms' strategic decisions on coopetition, and conversely, how coopetition has an impact on the nature of market competition.

3 Model description and assumption

To clearly depict the coopetition relationship, we consider two competing firms, indexed by $i \in \{1, 2\}$ and $j = 3 - i$, which sell similar products directly to end-users. The firms decide their own retail price p_i and service level s_i , respectively, and then achieve product demand q_i :

$$q_i = a - p_i + b(p_j - p_i) + s_i - k(s_j - s_i)$$

The competition coefficients are b and k , where $b \geq 0$ and $k \geq 0$ and measure the intensity of price and service competition between the two firms (Choi 1996; Tsay and Agrawal 2000). Higher values of b or k indicates higher levels of competition intensity of price or service, respectively. Consequently, the self-price sensitivity is defined as $1 + b$ and self-service sensitivity is defined as $1 + k$. This form of linear determinist demand function has been extensively used in economics (e.g., Vives 1999) and operations management literature (e.g., Shin and Tunca 2010; Ha et al. 2011; Shang et al. 2016). In addition, the two firms can make investments to improve their service levels, which will cost $I_i = \frac{1}{2}t_i s_i^2$, where t_i is an investment parameter defined as service-investment efficiency. This convex form of the service cost function suggests that the marginal cost of the provided service results in an additional unit service level, that is, improving unit service will be more difficult and requires more cost. The assumption is reasonable due to the “lowest-hanging fruit” consideration by a rational manager (Tsay and Agrawal 2000; Wu 2012; Chen et al. 2017). We denote our parameters and variables for model development as shown in Table 1.

Table 1. Parameters and variables

Notation	Descriptions
q_1, q_2	Customer demand of firms 1 and 2, respectively
p_1, p_2	Unit retail price of firms 1 and 2, respectively
s_1, s_2	Service level of firms 1 and 2, respectively
c	Unit manufacturing cost, $0 < c < p_1$ and $0 < c < p_2$
C_p, C_s, C_h	Cost of cooperation in pricing, service, and both competition factors in coopetition model with double competition factors
a	The primary market size, $a > 0$
b	Price competition coefficient, $b \geq 0$
k	Service competition coefficient, $k \geq 0$
t_1, t_2	An investment parameter and a function of service-investment efficiency of firms 1 and 2, respectively, $t_1, t_2 > 0$
I_1, I_2	The service investment of firms 1 and 2, respectively
M_i	$2(1+b)t_i - (1+k)^2$
N_i	$bt_i - (1+k)k$
A_i	$\frac{(a-c)(M_j + N_j)}{M_1M_2 - N_1N_2}$
X_i	$M_i - k^2$
Y_i	$N_i - k(1+k)$
Z_i	$2N_i$
B_i	$\frac{(a-c)(X_j + Y_j)}{X_1X_2 - Y_1Y_2}$
C_i	$\frac{(a-c)(X_j + Z_j)}{X_1X_2 - Z_1Z_2}$
D_i	$\frac{(a-c)[2(1+2b)t_j - (1+k)(1+2k)]}{2t_1[2(1+2b)t_2 - (1+k)(1+b+k)] + (1+k)[(1+k)(1+2k) - 2(1+b+k)t_2]}$
S	$\frac{(a-c)(t_2 - t_1)(1+2k)k}{X_1X_2 - Y_1Y_2}$
T	$\frac{(a-c)(t_2 - t_1)(1+2k)k}{X_1X_2 - Z_1Z_2}$

Note: The parameters from M_i to T are defined to simplify the mathematical expressions of propositions, lemmas, and their proofs.

Based on the above model description and assumption, the profit function of firm 1, denoted by $\pi_1(p_1, s_1)$, is

$$\pi_1(p_1, s_1) = (p_1 - c)q_1 - \frac{1}{2}t_1s_1^2 \quad (1)$$

The first term is the profit from product sale and the second term represents the service cost. Similarly, firm 2's profit, denoted by $\pi_2(p_2, s_2)$, is

$$\pi_2(p_2, s_2) = (p_2 - c)q_2 - \frac{1}{2}t_2s_2^2 \quad (2)$$

To ensure convexity of the profit functions of firms 1 and 2, we assume that $0 < k < \min\{\sqrt{2t_1(b+1)}, \sqrt{2t_2(b+1)}\} - 1$ for any $b \geq 0$ and $t_1, t_2 > 0$.

In the coopetition model with both price and service competition, we assume the cost of cooperation in pricing and service provision is C_p and C_s , respectively. In addition, the cost of cooperation both in pricing and service provisioning is C_h . Without loss of generality, the cost of dual element cooperation is larger than in the single element cooperation scenario (price or service), namely, $C_h > C_p$ and $C_h > C_s$. Therefore, the joint profit of firms 1 and 2, denoted by $\pi_\xi(p_1, s_1, p_2, s_2)$, is

$$\pi_\xi(p_1, s_1, p_2, s_2) = \pi_1(p_1, s_1) + \pi_2(p_2, s_2) - C_\xi \quad (3)$$

In the coopetition model, firm 1 and firm 2 share the cooperation cost with a contract parameter. A cost-sharing contract is introduced here, which is commonly employed in business practice. For example, a recent agreement between Morrisons, the fourth-largest supermarket in the United Kingdom, and Ocado, a leading online grocery retailer, enables the supermarket chain to expand online delivery service to a large region of England in 2017. Despite competing in the same online grocery market, the cooperation between the two firms through a contractual agreement of service cost-sharing ensures efficient resource use and strengthens their competitive capabilities over market rivals. Moreover, it is also easy to execute, since there is only one contract parameter that needs to be negotiated. Here, we assume that firm 1 shares β_ξ of the cooperation cost, while firm 2 shares $1 - \beta_\xi$ of it ($0 < \beta_\xi < 1$). Thus, in the coopetition model, the profit of firm 1 is $\pi_1(p_1, s_1) - \beta_\xi C_\xi$ and the profit of firm 2 is $\pi_2(p_2, s_2) - (1 - \beta_\xi)C_\xi$. The fraction β_ξ can be a cost-sharing contract between the two firms, which is determined when they engage in cooperation, where $\xi \in \{p, s, h\}$.

We assume that firms pursue self-interest and thus they can choose to cooperate on pricing and/or service with the rival firm to maximize their own profits. We attempt to analyze the impact of the strategic choice of coopetition on a firm's optimal operational decisions on price and service and its financial performance.

4 Service and price coopetition model

We start the analysis in a symmetric case that assumes the two firms' service-investment efficiencies are identical ($t_1 = t_2 = t$). We look at the following scenarios: (i) the competition model; (ii) the service

coopetition model; and (iii) the price coopetition model. We analyze the two firms' optimal solutions in the three scenarios, respectively, and explore the effect of the intensity of price and service competition on firm strategic choice.

4.1 Equilibrium in competition and coopetition models

In the competition model where customer demand is influenced by both price and service, firm 1 and firm 2 make their decisions separately to maximize their own profits. The decision problem of firm i is $\max_{p_i, s_i} \pi_i(p_i, s_i)$.

In the price coopetition model, firms 1 and 2 cooperate on price only. They make their decisions on service separately, but make pricing decisions jointly. Such practices are common in the iron ore industry, where large miners (e.g., Rio Tinto and BHP Billiton) cooperate on pricing decisions to avoid price wars and influence the market price. Meanwhile, decisions are made separately regarding the service level provided to their customers. Therefore, the decision problem of firm 1 is $\max_{s_1} \pi_1(p_1, s_1)$ and $\max_{p_1} \pi_p(p_1, s_1, p_2, s_2)$. Similarly, the decision problem of firm 2 is $\max_{s_2} \pi_2(p_2, s_2)$ and $\max_{p_2} \pi_p(p_1, s_1, p_2, s_2)$.

In the service coopetition model, firms 1 and 2 cooperate on service only. They make their pricing decisions separately and make service level decisions jointly. Using the agreement between Morrisons and Ocado as an example, the two grocery retailers make their own pricing decisions, and at the same time, they collaboratively make decisions on the delivery service to their customers and the service cost-sharing contract. Therefore, the decision problem of firm 1 is $\max_{p_1} \pi_1(p_1, s_1)$ and $\max_{s_1} \pi_s(p_1, s_1, p_2, s_2)$. Similarly, the decision problem of firm 2 is $\max_{p_2} \pi_2(p_2, s_2)$ and $\max_{s_2} \pi_s(p_1, s_1, p_2, s_2)$.

In the dual-element coopetition model, firms 1 and 2 cooperate on both price and service. They jointly make price and service level decisions. Using the strategic alliance in the airline industry as an example, major airlines collaboratively make decisions on price and service provision for the purpose of maximizing the financial benefit of the alliance and its collaborating firms. Therefore, the decision problem of firms 1 and 2 is $\max_{p_1, s_1, p_2, s_2} \pi_h(p_1, s_1, p_2, s_2)$.

Regarding the firms' optimal prices (\bar{p}_i^n) and service levels (\bar{s}_i^n) in the competition model, optimal

prices (\bar{p}_i^p) and service level (\bar{s}_i^p) in the price coopetition model, optimal prices (\bar{p}_i^s) and service level (\bar{s}_i^s) in the service coopetition model, and optimal prices (\bar{p}_i^h) and service level (\bar{s}_i^h) in the dual-element coopetition model when $t_1 = t_2 = t$, the following lemma is obtained.

Lemma 1. *There exist unique optimal pricing and service policies in the competition model, the price coopetition model, the service coopetition model, and the dual-element coopetition model when $t_1 = t_2 = t$, that is, $\bar{p}_i^n = c + \frac{(a-c)t}{(2+b)t-k-1}$, $\bar{p}_i^p = c + \frac{(a-c)t}{2t-k-1}$, $\bar{p}_i^s = c + \frac{(a-c)t}{(2+b)t-1}$, $\bar{p}_i^h = c + \frac{(a-c)t}{2t-1}$, $\bar{s}_i^n = \frac{(1+k)(a-c)}{(2+b)t-k-1}$, $\bar{s}_i^p = \frac{(1+k)(a-c)}{2t-k-1}$, $\bar{s}_i^s = \frac{(1+b)t(a-c)}{(2+b)t-1}$ and $\bar{s}_i^h = \frac{a-c}{2t-1}$.*

4.2 Effect of coopetition with both price and service competition

In this section, we focus on firms' strategic behavior and the effect of the competition and coopetition strategy on firm operational decisions and financial performance in a setting that considers both price and service competition. The following proposition can be obtained.

Proposition 1. *In the coopetition model that considers both price and service competition, if $k > bt$, then $\bar{p}_i^p > \bar{p}_i^n > \bar{p}_i^h > \bar{p}_i^s$, and if $k < bt$, then $\bar{p}_i^p > \bar{p}_i^h > \bar{p}_i^n > \bar{p}_i^s$. If $b < 2k$, then $\bar{s}_i^p > \bar{s}_i^n > \bar{s}_i^h > \bar{s}_i^s$; if $b > 2k$, then $\bar{s}_i^p > \bar{s}_i^h > \bar{s}_i^n > \bar{s}_i^s$.*

From this proposition, we see that the retail price is highest in the price coopetition model and lowest in the service coopetition model. The retail prices in the competition and dual-element coopetition models are somewhere in the middle. Therefore, we can conclude that price coopetition can weaken price competition, but intensify service competition, which leads to higher retail prices ($\bar{p}_i^p > \bar{p}_i^n$ and $\bar{p}_i^h > \bar{p}_i^s$)¹ and service levels ($\bar{s}_i^p > \bar{s}_i^n$ and $\bar{s}_i^h > \bar{s}_i^s$). In contrast, the service level is highest in the price competition model and lowest in the service coopetition model, while the competition and high coopetition models are somewhere in the middle. Therefore, we can conclude that service coopetition can also weaken service competition and intensify price competition that leads to lower retail prices ($\bar{p}_i^n > \bar{p}_i^s$ and $\bar{p}_i^p > \bar{p}_i^h$) and service levels ($\bar{s}_i^n > \bar{s}_i^s$ and $\bar{s}_i^p > \bar{s}_i^h$). For the relationship between the competition and dual-element coopetition models, the optimal decisions are dependent on price and service competition, as well as service-investment efficiency. All in all, we can summarize the above in the following remark.

Remark 1. *Coopetition will change the dynamics of price and service competition: cooperation*

¹ Note that a high coopetition model considered as price cooperation is executed in the service coopetition model; and one as service cooperation is executed in the price coopetition model.

on price (service) eases the intensity of price (service) competition, and at the same time, increases the intensity of service (price) competition.

Note that the maximum total profit of firms 1 and 2 in the competition model is $\pi_n = \pi_1(\bar{p}_1^n, \bar{s}_1^n) + \pi_2(\bar{p}_2^n, \bar{s}_2^n)$, $\pi_p = \pi_p(\bar{p}_1^p, \bar{s}_1^p, \bar{p}_2^p, \bar{s}_2^p)$, $\pi_s = \pi_s(\bar{p}_1^s, \bar{s}_1^s, \bar{p}_2^s, \bar{s}_2^s)$, and $\pi_f = \pi_f(\bar{p}_1^h, \bar{s}_1^h, \bar{p}_2^h, \bar{s}_2^h)$.

According to Lemma 1, we have $\pi_1(\bar{p}_1^n, \bar{s}_1^n) = \pi_2(\bar{p}_2^n, \bar{s}_2^n) = \frac{[2(1+b)t-(1+k)^2](a-c)^2t}{2[(2+b)t-k-1]^2}$,
 $\pi_1(\bar{p}_1^p, \bar{s}_1^p) = \frac{(a-c)^2[2t-(1+k)^2]t}{2(2t-1-k)^2} - \beta_p C_p$, $\pi_2(\bar{p}_2^p, \bar{s}_2^p) = \frac{(a-c)^2[2t-(1+k)^2]t}{2(2t-1-k)^2} - (1 - \beta_p)C_p$, $\pi_1(\bar{p}_1^s, \bar{s}_1^s) = \frac{[2(1+b)t-1](a-c)^2t}{2[(2+b)t-1]^2} - \beta_s C_s$, $\pi_2(\bar{p}_2^s, \bar{s}_2^s) = \frac{[2(1+b)t-1](a-c)^2t}{2[(2+b)t-1]^2} - (1 - \beta_s)C_s$, $\pi_1(\bar{p}_1^h, \bar{s}_1^h) = \frac{(a-c)^2t}{2(2t-1)} - \beta_h C_h$, $\pi_2(\bar{p}_2^h, \bar{s}_2^h) = \frac{(a-c)^2t}{2(2t-1)} - (1 - \beta_h)C_h$, $\pi_n = \frac{[2(1+b)t-(1+k)^2](a-c)^2t}{[(2+b)t-k-1]^2}$, $\pi_p = \frac{(a-c)^2[2t-(1+k)^2]t}{(2t-1-k)^2} - C_p$, $\pi_s = \frac{[2(1+b)t-1](a-c)^2t}{[(2+b)t-1]^2} - C_s$, and $\pi_h = \frac{(a-c)^2t}{2(2t-1)} - C_h$. The following lemma can be obtained.

Lemma 2. 1) Between the competition and price coopetition models, when $k < k^s$, there exists a curve $b = b^*(k)$ making $\pi_n|_{b=b^*(k)} = \pi_p$.

2) Between the competition and service coopetition models, when $b < b^p$, there exists a curve $k = k^*(b)$ making $\pi_n|_{k=k^*(b)} = \pi_s$.

3) Between the price coopetition and dual-element coopetition models, there exists a curve $k = k^s$ making $\pi_p|_{k=k^s} = \pi_h$.

4) Between the service coopetition and dual-element coopetition models, there exists a curve $b = b^p$ making $\pi_s|_{b=b^p} = \pi_h$.

From this lemma and its proof, we can clearly see that in the price coopetition model with dual competition elements, for any service competition coefficient k , there is a “reactive price competition” $b(k)$ where the strategic choice between competition and price coopetition makes no difference. When the price competition coefficient is lower than $b^*(k)$, the total profit of the competition mode is larger than in the price coopetition model ($\pi_n > \pi_p$); and when the price competition coefficient is higher than $b^*(k)$ where $k < k^s$, the total profit of the competition model is smaller than in the price coopetition model ($\pi_n < \pi_p$). Given the price coopetition model, there is a line $k = k^s$ where the strategic choice between price coopetition and high coopetition makes no difference. When the service competition is higher than a critical value k^s , the total profit in the high coopetition model is larger than in the price coopetition model ($\pi_p < \pi_h$).

In the service coopetition model with dual competition elements, for any price competition

coefficient b , there is a “reactive price competition” $k(b)$ where the strategic choice between competition and service coopetition makes no difference. Therefore, for any price competition coefficient b , when the actual service competition intensity is lower than $k^*(b)$, the total profit of the competition model is larger than the service coopetition model ($\pi_n > \pi_s$); and when the actual service competition is higher than $k^*(b)$ where $b < b^p$, the total profit of the competition model is smaller than the service coopetition model ($\pi_n < \pi_s$). Given the service coopetition model, there is a line $b = b^p$ where the strategic choice between service coopetition and high coopetition makes no difference. When the price competition is higher than a critical value b^p , the total profit in the high coopetition model is larger than in the service coopetition model ($\pi_s < \pi_h$).

Although we obtain the critical point (curve) that determines whether coopetition increases or decreases joint profits, to cooperate or not is also dependent on the cost-sharing contract parameter.

Corollary 1. 1) *When price competition is relatively high and the cost-sharing contract*

parameter satisfies $1 - \frac{bt^2\{2k(1+k)^2 - (1+k)[b+(4+b)k]t + 2bt^2\}(a-c)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2C_p} < \beta_p < \frac{bt^2\{2k(1+k)^2 - (1+k)[b+(4+b)k]t + 2bt^2\}(a-c)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2C_p}$, *where* $\frac{bt^2\{2k(1+k)^2 - (1+k)[b+(4+b)k]t + 2bt^2\}(a-c)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2C_p} > \frac{1}{2}$, *both firms are willing to cooperate on price instead of no cooperation;*

2) *When service competition is relatively high and the cost-sharing contract parameter satisfies*

$1 - \frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c)^2}{2[1+k-(2+b)t]^2[-1+(2+b)t]^2C_s} < \beta_s < \frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c)^2}{2[1+k-(2+b)t]^2[-1+(2+b)t]^2C_s}$, *where* $\frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c)^2}{2[1+k-(2+b)t]^2[-1+(2+b)t]^2C_s} > \frac{1}{2}$, *both firms are willing to cooperate on service instead of no cooperation;*

3) *When both price and service competition are relatively high and the cost-sharing contract*

parameter satisfies $1 - \frac{t^2(-2bk+2k^2+b^2t)(a-c)^2}{2(-1+2t)(1+k-(2+b)t)^2C_h} < \beta_h < \frac{t^2(-2bk+2k^2+b^2t)(a-c)^2}{2(-1+2t)(1+k-(2+b)t)^2C_h}$, *where* $\frac{t^2(-2bk+2k^2+b^2t)(a-c)^2}{2(-1+2t)(1+k-(2+b)t)^2C_h} > \frac{1}{2}$, *both firms are willing to cooperate on both price and service.*

This corollary shows us that the cost-sharing contract parameter, through which the cost can be divided between the two firms to ensure a win-win outcome of coopetition, is a favorable strategy for each firm in the price and service coopetition models. Therefore, from Lemma 2, we can obtain the following proposition, which provides the optimal solution for the strategic choice of competition or coopetition.

Proposition 2. *The curves $k = k^*(b)$, $b = b^*(k)$, $b = b^p$ and $k = k^s$ divide the two-*

dimensional competition and cooperation region into four decision areas, shown in Figure 1:

- 1) *Region I* $\{(b, k) | 0 < b < b^*(k) \cap 0 < k < k^*(b)\}$ where $0 < b < b^p$ and $0 < k < k^s$, competition only is the optimal strategy;
- 2) *Region II* $\{(b, k) | b > b^*(k) \cap 0 < k < k^s\}$, price cooperation is the optimal strategy;
- 3) *Region III* $\{(b, k) | 0 < b < b^p \cap k > k^*(b)\}$, service cooperation is the optimal strategy;
- 4) *Region IV* $\{(b, k) | b > b^p \cap k > k^s\}$, both price and service cooperation is the optimal strategy.

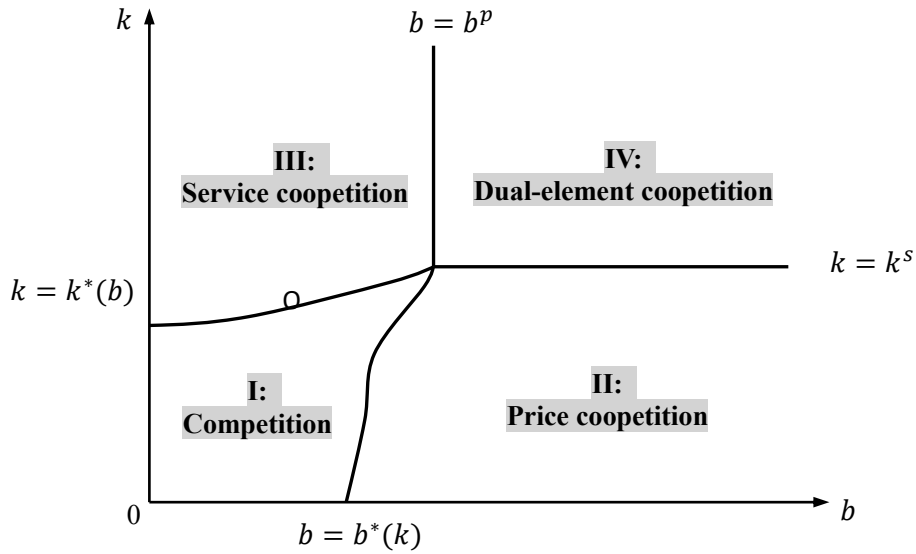


Figure 1. Cooperation mode selection based on both price and service competition

In the competitive market environment where rival firms compete with each other for customer demand using both price and service, excessive competition on price or service may lead to a pricing war with rival competitors or soaring service costs. As a result, such excessive competition will have a negative impact on a firm's financial performance. Firms can choose to ease the intensity of competition by cooperating with rival firms on price and/or service (Oxley et al. 2009). This proposition provides a clear guideline for such an important strategic decision. As illustrated in Figure 1, there are four decision regions specified by two decision curves, including competition strategy, price cooperation strategy, service cooperation strategy, and high cooperation strategy that involves both price and service cooperation.

For the rival firms, if price and service competition is relatively low, both firms will benefit from a competition strategy. They are able to achieve higher profits by competing purely with rival firms than by cooperating with rival firms on price and/or service. If service competition is relatively low, but price

competition intense, price cooperation is the best strategy for the rival firms. The high price competition intensity will drive firms to lower prices and lead to smaller profit margins. This finding is supported by the practice in the iron ore industry, where large miners engage in price cooperation, but not service cooperation. Price cooperation, on the one hand, can mitigate the risk of a pricing war; on the other hand, it will stimulate firms to raise service levels and consequently intensify service competition. If there is relatively low-price competition, but intense service competition, service cooperation is the most suitable strategy. This finding is supported by practices in the online grocery sector and the household appliance sector. In these sectors, the product prices are transparent in the market and there is low differentiation in prices between the major players. In contrast, consumers become more sensitive to the service level (i.e., delivery service for online grocery retailers and aftersales service for household appliance manufacturers). Consequently, these firms are more likely to engage in service cooperation than price cooperation. The high service competition intensity will force firms to raise their service levels, which requires a larger service investment. The service cooperation, on the one hand, can reduce the required investment by easing the service competition intensity, but on the other hand, provide incentives to firms to reduce retail prices in order to trigger more customer demand and consequently intensify price competition. If there is intense price and service competition, either price or service cooperation alone is only a suboptimal solution and there always exists Pareto optimality. A high cooperation mode that includes both price and service cooperation is the right strategic choice, which is supported by the strategic alliance example in the airline industry. We summarize the above findings in the following remark.

Remark 2. *The strategic choice of competition, price cooperation, service cooperation, or price and service cooperation is dependent on the intensity of the price and service competition, and the appropriate design of the cooperation cost-sharing contract.*

5 Extended model: the asymmetric case

The analytical results in the previous section are obtained under the assumption that the two firms have the same service-investment efficiency. To generalize our findings, we look at firms' strategic behavior regarding cooperation and its effect on operational decisions and financial performance when service-investment efficiency differs between the two firms, namely, $t_1 \neq t_2$. Without loss of generality, we

assume $t_1 < t_2$. That is, the service-investment efficiency of firm 1 is higher than that of firm 2.

5.1 Equilibrium in the coopetition models

This part of analysis provides the optimal pricing and service level policies in the asymmetric case. The firms' optimal prices (p_i^n) and service levels (s_i^n) in the competition model, optimal prices (p_i^p) and service levels (s_i^p) in the price coopetition model, optimal prices (p_i^s) and service levels (s_i^s) in the service coopetition model, and optimal prices (p_i^h) and service levels (s_i^h) in the dual-element coopetition model, are obtained as illustrated in the following lemma.

Lemma 3. *There exist unique optimal pricing and service policies in the competition model, the price coopetition model, the service coopetition model, and dual-element coopetition model, which are summarized in Table 2.*

Table 2. Optimal policies with both price and service competition

	Competition ($\xi = n$)	Price coopetition ($\xi = p$)	Service coopetition ($\xi = s$)	Dual-element coopetition ($\xi = h$)
p_1^ξ	$c + t_1 A_1$	$c + t_1 D_1$	$c + t_1 B_1 - S$	$c + t_1 C_1 - T$
p_2^ξ	$c + t_2 A_2$	$c + t_2 D_2$	$c + t_2 B_2 + S$	$c + t_2 C_2 + T$
s_1^ξ	$(1 + k)A_1$	$(1 + k)D_1$	B_1	C_1
s_2^ξ	$(1 + k)A_2$	$(1 + k)D_2$	B_2	C_2

Note: the proof can be found in the proof of Lemma 3.

5.2 Effect of service-investment efficiency on decisions

Now we analyze the effect of service-investment efficiency on firms' optimal solution of pricing and service level. The following proposition can be obtained.

Proposition 3. *If $t_1 < t_2$, then $p_1^\xi > p_2^\xi$ and $s_1^\xi > s_2^\xi$; if $t_1 = t_2$, then $p_1^\xi = p_2^\xi$ and $s_1^\xi = s_2^\xi$; if $t_1 > t_2$, then $p_1^\xi < p_2^\xi$ and $s_1^\xi < s_2^\xi$, where $\xi \in \{n, s, p, h\}$.*

Here, $t_1 < t_2$ means that the service-investment efficiency of firm 1 is higher than that of firm 2. Hence, from this proposition, we know that the firm with high service-investment efficiency will provide higher service levels than that with low service-investment efficiency. It is logical for firms to behave in this way, as most firms will maximize the benefit of their competitive advantages. In this case, high service-investment efficiency incentivizes the firm to invest more on service to increase its customer demand. Meanwhile, the increased demand from the high service level enables the firm to set relatively

higher retail prices in order to achieve higher marginal profits and lower the expense ratio.

5.3 Effect of service-investment efficiency on strategic choice

We now examine the impact of service-investment efficiency on firms' optimal strategic decision on cooperation in the asymmetric case. As the analytical solution in the asymmetric case is more complicated than that in the symmetric case, a numerical analysis is presented to illustrate the impact. Here, we specify that $a = 200$, $c = 20$, $t_1 = 200$ and $t_2 = 300$, $C_p = 1500$, and $C_s = 200$. In the scenarios with different price and service competition intensity, we provide the firm's optimal strategic choice between competition and cooperation, as shown in Figure 2.

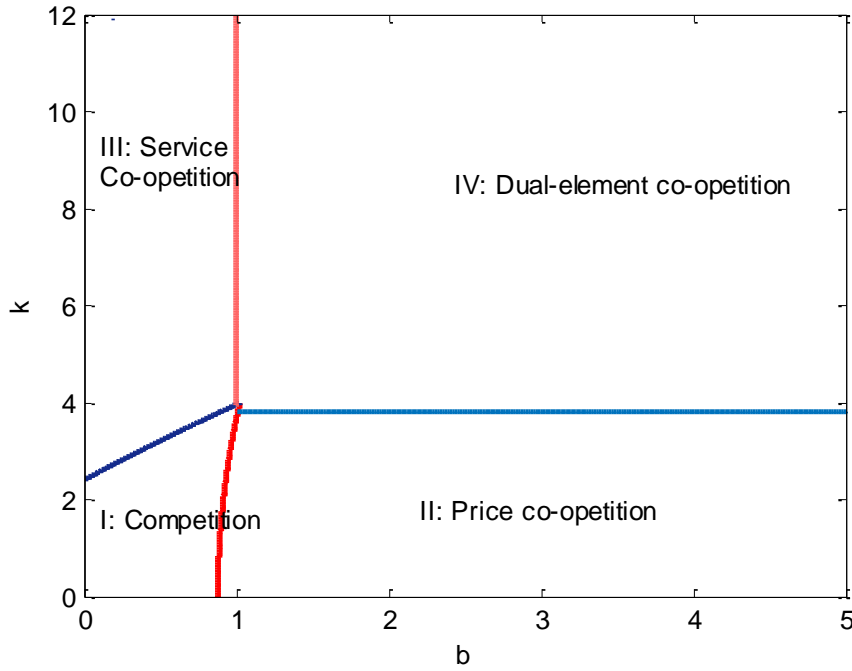


Figure 2. Cooperation strategy choice based on both price and service competition

From Figure 2, we find that, in the asymmetric case where the service-investment efficiency is different between the two firms, the optimal strategic choice on cooperation is similar to that in the asymmetric case (see Figure 1). We can clearly see that competition (Region I) is suitable for the situation when the intensity of both price and service competition is relatively low. In contrast, when both price and service competition intensity is high (Region IV), a high level of cooperation, which includes both price and service cooperation, is the optimal strategy. However, in the situation where one element (e.g., price or service) dominates market competition, the optimal strategy for the rival firms is to cooperate on this element. This further demonstrates that the strategic choice between competition and cooperation is mainly determined by the intensity of price and service competition.

From Lemma 3, Proposition 3, and Figure 2, it is clear that the service-investment efficiency (t_1, t_2) makes an impact on firms' optimal operational decisions (i.e., prices and service level) as well as the value of important critical decision curves that influence firms' optimal decisions on coopetition strategy. Nevertheless, the structural results presented in the symmetric case (Section 4) still hold in the asymmetric case when the firms have different service-investment efficiency ($t_1 \neq t_2$). The above findings are summarized in the following remark.

Remark 3: The internal operations capability (i.e., difference in service-investment efficiency) affects firms' optimal decisions on price and service, but has a limited impact on the strategic decision on coopetition. In contrast, the strategic choice between competition and coopetition is mainly determined by the external market characteristics (i.e., the competition intensity of price and service), and it applies to both the symmetric and asymmetric cases.

6 Conclusions

This research explores optimal firm coopetition strategy, considering the intensity of competition and the dynamics of coopetition. First, coopetition models are developed in which the two firms are assumed to have the same service-investment efficiency. We examine the impact of strategic choice between competition and coopetition through comparing the optimal solutions on pricing and service level and optimal profits in various competition and coopetition models. We then extend our analysis to the asymmetric case in which the two firms have different service-investment efficiencies. Based on the analysis, a decision framework for coopetition strategy is proposed for both symmetric and asymmetric scenarios. The decision framework enables firms to make optimal strategic decisions on coopetition under various market conditions. The main research findings are as follows.

The strategic decision on coopetition (e.g., whether to compete or cooperate with a competitor and how to cooperate) depends on the intensity of the market competition. This finding supports the view of Oxley et al. (2009) and Ritala (2012), who claim that the success of coopetition strategies is affected by competition intensity. The same rule applies to both single- and dual-element coopetition. In the single-element coopetition scenario, rival firms will choose to compete only if there is low service (price) competition, and they will prefer to cooperate on service (price) if there is high service (price) competition in this single element. For the dual-element competition scenario, rival firms will choose to

compete on the element(s) (e.g., price and/service) if there is low intensity of price and/or service competition(s). In contrast, they will prefer to cooperate on price and/or service if there is high price and/or service competition. The above findings also apply to both symmetric and asymmetric cases in terms of service-investment efficiency. Furthermore, our analyses show that coopetition changes the dynamics of the competition and cooperation between the two rival firms. For instance, on the one hand, the coopetition eases the competition intensity of the cooperating element (e.g., price or service). On the other hand, the coopetition increases the competition intensity of the non-cooperating element, as the rival firms have to differentiate themselves in order to compete for customer demand. When the competition intensity reaches a critical point, it will also affect firms' optimal coopetition strategies, and they may be worse off financially if they stick with the chosen coopetition strategy.

The decision framework that includes coopetition along both price and service dimensions provides a richer representation of firms' strategic behavior on coopetition. It suggests a broader set of decision outcomes than the traditional models that focus primarily on single-element coopetition, such as innovation or technology (Gnyawali and Park 2011; Luo et al. 2016). Considering the dynamic nature of the competition and cooperation duality (Luo 2007; Dahl 2014; Dorn et al. 2016), our exploration of the dynamics of coopetition can help researchers and managers better understand how an increase or decrease in competition will affect the benefits of coopetition strategies, and how the nature of competition is affected by changing organizational or environmental conditions triggered by coopetition decisions. In addition, the intensity, diversity, and dynamics of coopetition captured and explored in our analytical modeling are an important supplement to existing studies (Luo 2007; Ritala 2012; Dorn et al. 2016) that highlight these areas as key issues to advance coopetition research.

There are several directions for future investigations. First, this research only considers a dyadic coopetition relationship. However, as discussed in the literature, coopetition can also take place at the network level (e.g., Gnyawali et al. 2006; Peng and Bourne 2009; Schiavone and Simoni 2011) and a network setting may affect firms' strategic and operational decisions regarding coopetition. Therefore, it would be interesting to explore the optimal coopetition strategy at the network level. Second, a linear additive deterministic demand function is adopted in this study. Although it has the advantage of being analytically more tractable and is widely applied in similar studies (Ha et al. 2011; Chen and Wang 2015; Shang et al. 2016), market uncertainty is one of the critical factors affecting the success of coopetition strategies (Ritala 2012). One future extension would be to investigate the research problem using

stochastic models to explore how demand uncertainty might influence the results. Finally, our coopetition models consider generic forms of coopetition, such as price and service. Although it has the advantage of allowing our findings to be generalized to various business environments, the research can be further improved by incorporating specific settings in the modeling to reflect the nature of businesses and their marketing environments. This would be an interesting case to consider; however, because it requires a very different mode of analysis, it is left for further research.

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Appendix

Proof of Lemma 1

Competition: From (1), we get $\frac{\partial \pi_1(p_1, s_1)}{\partial p_1} = a - p_1 - (1 + b)(p_1 - c) + b(p_2 - p_1) + s_1 - k(s_2 - s_1)$ and $\frac{\partial \pi_1(p_1, s_1)}{\partial s_1} = (1 + k)(p_1 - c) - t_1 s_1$. Then, we obtain $\frac{\partial \pi_1^2(p_1, s_1)}{\partial p_1^2} = -2 - 2b$, $\frac{\partial \pi_1^2(p_1, s_1)}{\partial s_1^2} = -t_1$, and $\frac{\partial \pi_1^2(p_1, s_1)}{\partial p_1 \partial s_1} = \frac{\partial \pi_1^2(p_1, s_1)}{\partial s_1 \partial p_1} = 1 + k$, and $\begin{vmatrix} -2 - 2b & 1 + k \\ 1 + k & -t_1 \end{vmatrix} = 2t_1(b + 1) - (k + 1)^2 > 0$.

Therefore, $\pi_1(p_1, s_1)$ is a concave function of p_1 and s_1 .

From (2), we obtain $\frac{\partial \pi_2(p_2, s_2)}{\partial p_2} = a + b(p_1 - p_2) - p_2 - (1 + b)(p_2 - c) - k(s_1 - s_2) + s_2$ and $\frac{\partial \pi_2(p_2, s_2)}{\partial s_2} = (1 + k)(p_2 - c) - t_2 s_2$. Then, $\frac{\partial \pi_2^2(p_2, s_2)}{\partial p_2^2} = -2 - 2b$, $\frac{\partial \pi_2^2(p_2, s_2)}{\partial s_2^2} = -t_2$, and $\frac{\partial \pi_2^2(p_2, s_2)}{\partial p_2 \partial s_2} = \frac{\partial \pi_2^2(p_2, s_2)}{\partial s_2 \partial p_2} = 1 + k$. So, $\begin{vmatrix} -2 - 2b & 1 + k \\ 1 + k & -t_2 \end{vmatrix} = 2t_2(b + 1) - (k + 1)^2 > 0$. Therefore, $\pi_2(p_2, s_2)$ is a concave function of p_2 and s_2 .

Let $\frac{\partial \pi_1(p_1, s_1)}{\partial p_1} = \frac{\partial \pi_1(p_1, s_1)}{\partial s_1} = \frac{\partial \pi_2(p_2, s_2)}{\partial p_2} = \frac{\partial \pi_2(p_2, s_2)}{\partial s_2} = 0$, we get $p_1^n = c + t_1 A_1$, $p_2^n = c + t_2 A_2$, $s_1^n = (1 + k)A_1$, and $s_2^n = (1 + k)A_2$. When $t_1 = t_2 = t$, we have $\bar{p}_i^n = c + \frac{(a-c)t}{(2+b)t-k-1}$ and $\bar{s}_i^n = \frac{(1+k)(a-c)}{(2+b)t-k-1}$.

Pricing coopetition: From (3), we get $\frac{\partial \pi_p(p_1, s_1, p_2, s_2)}{\partial p_1} = a - p_1 - (1 + b)(p_1 - c) + b(p_2 - c) + b(p_2 - p_1) + s_1 - k(s_2 - s_1)$ and $\frac{\partial \pi_p(p_1, s_1, p_2, s_2)}{\partial p_2} = a + b(p_1 - c) + b(p_1 - p_2) - p_2 - (1 + b)(p_2 - c) - k(s_1 - s_2) + s_2$. Then, we obtain $\frac{\partial \pi_p^2(p_1, s_1, p_2, s_2)}{\partial p_1^2} = -2 - 2b$, $\frac{\partial \pi_p^2(p_1, s_1, p_2, s_2)}{\partial p_2^2} = -2 - 2b$, and $\frac{\partial \pi_p^2(p_1, s_1, p_2, s_2)}{\partial p_1 \partial p_2} = \frac{\partial \pi_p^2(p_1, s_1, p_2, s_2)}{\partial p_2 \partial p_1} = 2b$, then $\begin{vmatrix} -2 - 2b & 2b \\ 2b & -2 - 2b \end{vmatrix} = 4 + 8b > 0$. Therefore, $\pi_p(p_1, s_1, p_2, s_2)$ is a concave function of p_1 and p_2 .

From (1), we get $\frac{d\pi_1(p_1, s_1)}{ds_1} = (1+k)(p_1 - c) - s_1 t_1$ and $\frac{d\pi_1^2(p_1, s_1)}{ds_1^2} = -t_1 < 0$. Therefore, $\pi_1(p_1, s_1)$ is a concave function of s_1 . Similarly, from (2), we get $\frac{d\pi_2(p_2, s_2)}{ds_2} = (1+k)(p_2 - c) - s_2 t_2$ and $\frac{d\pi_2^2(p_2, s_2)}{ds_2^2} = -t_2 < 0$. Therefore, $\pi_2(p_2, s_2)$ is a concave function of s_2 .

Letting $\frac{\partial \pi_p(p_1, s_1, p_2, s_2)}{\partial p_1} = \frac{\partial \pi_p(p_1, s_1, p_2, s_2)}{\partial p_2} = \frac{d\pi_1(p_2, s_2)}{ds_1} = \frac{d\pi_2(p_2, s_2)}{ds_2} = 0$, we get $p_1^p = c + t_1 D_1$, $p_2^p = c + t_2 D_2$, $s_1^p = (1+k)D_1$, and $s_2^p = (1+k)D_2$. When $t_1 = t_2 = t$, we have $\bar{p}_i^p = c + \frac{(a-c)t}{2t-k-1}$ and $\bar{s}_i^p = \frac{(1+k)(a-c)}{2t-k-1}$.

Service coopetition: From (3), we get $\frac{\partial \pi_s(p_1, s_1, p_2, s_2)}{\partial s_1} = (1+k)(p_1 - c) - k(p_2 - c) - t_1 s_1$ and $\frac{\partial \pi_s(p_1, s_1, p_2, s_2)}{\partial s_2} = -k(p_1 - c) + (1+k)(p_2 - c) - t_2 s_2$. Then, we obtain $\frac{\partial \pi_s^2(p_1, s_1, p_2, s_2)}{\partial s_1^2} = -t_1$, $\frac{\partial \pi_s^2(p_1, s_1, p_2, s_2)}{\partial s_2^2} = -t_2$, and $\frac{\partial \pi_s^2(p_1, s_1, p_2, s_2)}{\partial s_1 \partial s_2} = \frac{\partial \pi_s^2(p_1, s_1, p_2, s_2)}{\partial s_2 \partial s_1} = 0$, and $\begin{vmatrix} -t_1 & 0 \\ 0 & -t_2 \end{vmatrix} = t_1 t_2 > 0$. Therefore, $\pi_s(p_1, s_1, p_2, s_2)$ is a concave function of s_1 and s_2 .

From (1), we get $\frac{d\pi_1(p_1, s_1)}{dp_1} = a - p_1 - (1+b)(p_1 - c) + b(p_2 - p_1) + s_1 - k(s_2 - s_1)$ and $\frac{d\pi_1^2(p_1, s_1)}{dp_1^2} = -2 - 2b < 0$. Therefore, $\pi_1(p_1, s_1)$ is a concave function of p_1 . Similarly, from (2), we get $\frac{d\pi_2(p_2, s_2)}{dp_2} = a + b(p_1 - p_2) - p_2 - (1+b)(p_2 - c) - k(s_1 - s_2) + s_2$ and $\frac{d\pi_2^2(p_2, s_2)}{dp_2^2} = -2 - 2b < 0$. Therefore, $\pi_2(p_2, s_2)$ is a concave function of p_2 .

Letting $\frac{\partial \pi_s(p_1, s_1, p_2, s_2)}{\partial s_1} = \frac{\partial \pi_s(p_1, s_1, p_2, s_2)}{\partial s_2} = \frac{d\pi_1(p_2, s_2)}{dp_1} = \frac{d\pi_2(p_2, s_2)}{dp_2} = 0$, we get $p_1^s = c + t_1 B_1 - S$, $p_2^s = c + t_2 B_2 + S$, $s_1^s = B_1$, and $s_2^s = B_2$. When $t_1 = t_2 = t$, we have $\bar{p}_i^s = c + \frac{(a-c)t}{(2+b)t-1}$ and $\bar{s}_i^s = \frac{(1+b)t(a-c)}{(2+b)t-1}$.

High coopetition: From (3), we get $\frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial p_1} = a + c - 2p_1 - 2bp_1 + 2bp_2 + s_1 + ks_1 - ks_2$ and $\frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial s_1} = -c + p_1 + kp_1 - kp_2 - s_1 t_1$. Then, we get $\frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial p_1^2} = -2 - 2b$, $\frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial s_1^2} = -t_1$ and $\frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial p_1 \partial s_1} = \frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial s_1 \partial p_1} = 1 + k$. So, we get $\begin{vmatrix} -2-2b & 1+k \\ 1+k & -t_1 \end{vmatrix} = 2t_1(1+b) - (1+k)^2 > 0$. Therefore, $\pi_h(p_1, s_1, p_2, s_2)$ is a concave function of p_1 and s_1 .

Similarly, we get $\frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial p_2} = a + c + 2bp_1 - 2p_2 - 2bp_2 - ks_1 + s_2 + ks_2$ and $\frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial s_2} = -c - kp_1 + p_2 + kp_2 - s_2 t_2$. Then, we get $\frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial p_2^2} = -2 - 2b$,

$$\frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial s_2^2} = -t_2, \text{ and } \frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial p_2 \partial s_2} = \frac{\partial \pi_h^2(p_1, s_1, p_2, s_2)}{\partial s_2 \partial p_2} = 1 + k. \text{ Thus, we get } \begin{vmatrix} -2-2b & 1+k \\ 1+k & -t_2 \end{vmatrix} =$$

$2t_2(1+b) - (1+k)^2 > 0$. Therefore, $\pi_h(p_1, s_1, p_2, s_2)$ is a concave function of p_2 and s_2 .

Letting $\frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial p_1} = \frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial s_1} = \frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial p_2} = \frac{\partial \pi_h(p_1, s_1, p_2, s_2)}{\partial s_2} = 0$, we get $p_1^h = c + t_1 C_1 - T$, $p_2^h = c + t_2 C_2 + T$, $s_1^h = C_1$, and $s_2^h = C_2$. When $t_1 = t_2 = t$, we have $\bar{p}_i^h = c + \frac{(a-c)t}{2t-1}$ and $\bar{s}_i^h = \frac{a-c}{2t-1}$.

Proof of Proposition 1:

For the retail prices, we have $\bar{p}_i^n - \bar{p}_i^s = \frac{kt(a-c)}{(2t+bt-1-k)(2t+bt-1)} > 0$, $\bar{p}_i^n - \bar{p}_i^p = -\frac{bt^2(a-c)}{(2t+bt-1-k)(2t+bt-1)} < 0$, $\bar{p}_i^p - \bar{p}_i^s = \frac{t(k+bt)(a-c)}{(2t-1-k)(2t+bt-1)} > 0$, $\bar{p}_i^s - \bar{p}_i^h = -\frac{bt^2(a-c)}{(-1+2t)(-1+2t+bt)} < 0$, and $\bar{p}_i^p - \bar{p}_i^h = \frac{kt(a-c)}{(1+k-2t)(-1+2t)} > 0$. Since $\bar{p}_i^n - \bar{p}_i^h = \frac{t(k-bt)(a-c)}{(-1+2t)(-1-k+2t+bt)}$, if $k > bt$, then $\bar{p}_i^p > \bar{p}_i^n > \bar{p}_i^h > \bar{p}_i^s$, and if $k < bt$, then $\bar{p}_i^p > \bar{p}_i^h > \bar{p}_i^n > \bar{p}_i^s$.

For the service level, we have $\bar{s}_i^n - \bar{s}_i^s = \frac{(2+b)kt(a-c)}{(2t+bt-1-k)(2t+bt-1)} > 0$, $\bar{s}_i^n - \bar{s}_i^p = -\frac{b(1+k)t(a-c)}{(2t-1-k)(2t+bt-1-k)} < 0$, $\bar{s}_i^p - \bar{s}_i^s = \frac{(b+2k+bk)t(a-c)}{(2t-1-k)(2t+bt-1)} > 0$, $\bar{s}_i^s - \bar{s}_i^h = -\frac{bt(a-c)}{(-1+2t)(-1+2t+bt)} < 0$, and $\bar{s}_i^p - \bar{s}_i^h = \frac{2kt(a-c)}{(2t-1-k)(-1+2t)} > 0$. Since $\bar{s}_i^n - \bar{s}_i^h = \frac{(-b+2k)t(a-c)}{(-1+2t)(-1-k+2t+bt)}$, if $b < 2k$, then $\bar{s}_i^p > \bar{s}_i^n > \bar{s}_i^h > \bar{s}_i^s$; if $b > 2k$, then $\bar{s}_i^p > \bar{s}_i^h > \bar{s}_i^n > \bar{s}_i^s$.

Proof of Lemma 2: When $t_1 = t_2 = t$, we have $\pi_n = \frac{[2(1+b)t-(1+k)^2](a-c)^2 t}{[(2+b)t-k-1]^2}$, $\pi_p =$

$$\frac{(a-c)^2[2t-(1+k)^2]t}{(2t-1-k)^2} - C_p, \pi_s = \frac{[2(1+b)t-1](a-c)^2 t}{[(2+b)t-1]^2} - C_s, \text{ and } \pi_h = \frac{(a-c)^2 t}{2(2t-1)} - C_h.$$

$\pi_p - \pi_n = \frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{(1+k-2t)^2(1+k-(2+b)t)^2} - C_p$. When $b = 0$, then $\pi_p - \pi_n = -C_p < 0$. When $b > 0$, we have $\frac{d(\pi_p - \pi_n)}{dk} = \frac{2t^2(bt-k-k^2)(a-c_m)^2}{[(2+b)t-1-k]^3}$, so if $bt-k-k^2 < 0$, then $\frac{d(\pi_p - \pi_n)}{dk} < 0$, namely, $\pi_p - \pi_n$ is decreasing in k . Therefore, if $bt-k-k^2 < 0$, $\pi_p < \pi_n$. If $bt-k-k^2 > 0$, then $\frac{d(\pi_p - \pi_n)}{dk} > 0$, namely, $\pi_p - \pi_n$ is increasing in b . When $b \rightarrow \infty$, we can get $\lim_{b \rightarrow \infty} (\pi_p - \pi_n) = \pi_p > 0$. Therefore, there must be $b = b^*(k)$ that makes $\pi_p = \pi_n$.

$$\pi_s - \pi_n = \frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c_m)^2}{[1+k-(2+b)t]^2[-1+(2+b)t]^2} - C_s. \text{ When } k = 0, \text{ then } \pi_s - \pi_n = -C_s < 0.$$

When $k > 0$, we have $\frac{d(\pi_s - \pi_n)}{dk} = \frac{2[b(-1+k)+2k]t^2(a-c_m)^2}{[(2+b)t-1-k]^3}$, so if $-b + 2k + bk < 0$, then $\frac{d(\pi_s - \pi_n)}{dk} < 0$, namely, $\pi_s - \pi_n$ is decreasing in k . Therefore, if $-b + 2k + bk < 0$, $\pi_s < \pi_n$. If $-b + 2k + bk > 0$, then $\frac{d(\pi_s - \pi_n)}{dk} > 0$, namely, $\pi_s - \pi_n$ is increasing in k . When $k \rightarrow \infty$, we can get $\lim_{k \rightarrow \infty} (\pi_s - \pi_n) = \frac{2(a-c)^2 t^2}{2t-1} - c_{c1} = \pi_s + (a-c)^2 t > 0$. Therefore, there must be $k = k^*(b)$ making $\pi_s = \pi_n$.

$\pi_h - \pi_p = \frac{2k^2 t^2 (a-c_m)^2}{(1+k-2t)^2(-1+2t)} - C_h + C_p$. When $k = 0$, $\pi_h - \pi_p = -C_h + C_p < 0$ since $C_h > C_p$. When $k > 0$, we have $\frac{d(\pi_h - \pi_p)}{dk} = \frac{4kt^2(a-c)^2}{(-1-k+2t)^3} > 0$, that is, $\pi_h - \pi_p$ is increasing in k . When $k \rightarrow \infty$, we can get $\lim_{k \rightarrow \infty} (\pi_h - \pi_p) = \frac{2t^2(a-c)^2}{2t-1} - C_h + C_p = \pi_h + C_p + \frac{t(4t-1)(a-c)^2}{2t-1} > 0$. Therefore, there must be a $k = k^s$ that makes $\pi_h = \pi_p$.

$\pi_h - \pi_s = \frac{b^2 t^3 (a-c_m)^2}{(-1+2t)(-1+(2+b)t)^2} - C_h + C_s$. When $b = 0$, $\pi_h - \pi_s = -C_h + C_s < 0$ since $C_h > C_s$. When $b > 0$, we have $\frac{d(\pi_h - \pi_s)}{db} = \frac{2bt^3(a-c)^2}{(-1+2t+bt)^3} > 0$, that is, $\pi_h - \pi_s$ is increasing in b . When $b \rightarrow \infty$, we can get $\lim_{b \rightarrow \infty} (\pi_h - \pi_s) = \frac{2(a-c)^2 t}{2t-1} - C_h + C_s = \pi_h + \frac{(a-c)^2 t}{2(2t-1)} + C_s > 0$. Therefore, there must be a $b = b^p$ that makes $\pi_h = \pi_s$.

Proof of Corollary 1: 1) When $t_1 = t_2 = t$, $\pi_1(\bar{p}_1^p, \bar{s}_1^p) - \pi_1(\bar{p}_1^n, \bar{s}_1^n) = \frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2} - \beta_p C_p$ and $\pi_2(\bar{p}_2^p, \bar{s}_2^p) - \pi_2(\bar{p}_2^n, \bar{s}_2^n) = \frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2} - (1-\beta_p)C_p$. When $b > b^*(k)$, the necessary condition that makes the two firms cooperate satisfies $\pi_1(\bar{p}_1^p, \bar{s}_1^p) - \pi_1(\bar{p}_1^n, \bar{s}_1^n) > 0$ and $\pi_2(\bar{p}_2^p, \bar{s}_2^p) - \pi_2(\bar{p}_2^n, \bar{s}_2^n) > 0$. From the proof of Lemma 4, $b > b^*(k)$ and $\pi_p - \pi_n = \frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{(1+k-2t)^2(1+k-(2+b)t)^2} - C_p$ gives $\frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2 C_p} > \frac{1}{2}$. Therefore, the parameter should satisfy $1 - \frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2 C_p} < \beta_p < \frac{bt^2\{2k(1+k)^2-(1+k)[b+(4+b)k]t+2bt^2\}(a-c_m)^2}{2(1+k-2t)^2(1+k-(2+b)t)^2 C_p}$.

2) When $t_1 = t_2 = t$, $\pi_1(\bar{p}_1^s, \bar{s}_1^s) - \pi_1(\bar{p}_1^n, \bar{s}_1^n) = \frac{kt^2(2b-2k+(2+b)(b(-2+k)+2k)t)(a-c_m)^2}{2(1+k-(2+b)t)^2(-1+(2+b)t)^2} - \beta_s C_s$ and $\pi_2(\bar{p}_2^s, \bar{s}_2^s) - \pi_2(\bar{p}_2^n, \bar{s}_2^n) = \frac{kt^2(2b-2k+(2+b)(b(-2+k)+2k)t)(a-c_m)^2}{2(1+k-(2+b)t)^2(-1+(2+b)t)^2} - (1-\beta_s)C_s$. When $k >$

$k^*(b)$, the necessary condition that makes the two firms cooperate satisfies $\pi_1(\bar{p}_1^s, \bar{s}_1^s) - \pi_1(\bar{p}_1^n, \bar{s}_1^n) > 0$ and $\pi_2(\bar{p}_2^s, \bar{s}_2^s) - \pi_2(\bar{p}_2^n, \bar{s}_2^n) > 0$. From the proof of Lemma 4, $k > k^*(b)$ and $\pi_s - \pi_n = \frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c_m)^2}{[1+k-(2+b)t]^2[-1+(2+b)t]^2} - C_s$ gives $\frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c_m)^2}{2[1+k-(2+b)t]^2[-1+(2+b)t]^2C_s} > \frac{1}{2}$. Therefore, the parameter should satisfy $1 - \frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c_m)^2}{2[1+k-(2+b)t]^2[-1+(2+b)t]^2C_s} < \beta_s < \frac{kt^2\{2b-2k+(2+b)[b(-2+k)+2k]t\}(a-c_m)^2}{2[1+k-(2+b)t]^2[-1+(2+b)t]^2C_s}$.

3) When $t_1 = t_2 = t$, $\pi_1(\bar{p}_1^h, \bar{s}_1^h) - \pi_1(\bar{p}_1^n, \bar{s}_1^n) = \frac{t^2(-2bk+2k^2+b^2t)(a-c_m)^2}{2(-1+2t)(1+k-(2+b)t)^2} - \beta_h C_h$ and $\pi_2(\bar{p}_2^h, \bar{s}_2^h) - \pi_2(\bar{p}_2^n, \bar{s}_2^n) = \frac{t^2(-2bk+2k^2+b^2t)(a-c_m)^2}{2(-1+2t)(1+k-(2+b)t)^2} - (1 - \beta_h)C_h$. When $k > k^s$ and $b > b^p$, the necessary condition that makes the two firms cooperate satisfies $\pi_1(\bar{p}_1^h, \bar{s}_1^h) - \pi_1(\bar{p}_1^n, \bar{s}_1^n) > 0$ and $\pi_2(\bar{p}_2^h, \bar{s}_2^h) - \pi_2(\bar{p}_2^n, \bar{s}_2^n) > 0$. From Lemma 4, when $k > k^s$ and $b > b^p$, $\pi_f > \pi_n$ gives $\frac{t^2(-2bk+2k^2+b^2t)(a-c)^2}{2(-1+2t)(1+k-(2+b)t)^2C_h} > \frac{1}{2}$. Therefore, the parameter should satisfy $1 - \frac{t^2(-2bk+2k^2+b^2t)(a-c)^2}{2(-1+2t)(1+k-(2+b)t)^2C_h} < \beta_h < \frac{t^2(-2bk+2k^2+b^2t)(a-c)^2}{2(-1+2t)(1+k-(2+b)t)^2C_h}$.

Proof of Proposition 2: From Lemma 2, in the region $\{(b, k) | 0 < k < k^*(b) \cap 0 < b < b^*(k)\}$ where $0 < b < b^p$ and $0 < k < k^s$, we have $\pi_n > \pi_p$ and $\pi_n > \pi_s$, thus, the competition mode is optimal. In the region $\{(b, k) | 0 < k < k^s \cap b > b^*(k)\}$, we have $\pi_p < \pi_n$, thus, the pricing cooperation mode is optimal. In the region $\{(b, k) | k > k^*(b) \cap 0 < b < b^p\}$, we have $\pi_s < \pi_n$, thus, the service cooperation mode is optimal. Finally, in the region $\{(b, k) | k > k^s \cap b > b^p\}$, we have $\pi_h > \pi_p$ and $\pi_h > \pi_s$, high cooperation; that is, cooperation in both price and service cooperation is optimal.

Proof of Proposition 3:

From Table 2, we get $p_1^n - p_2^n = t_1 A_1 - t_2 A_2 = \frac{(a-c_m)(1+k)(1+2k)(t_2-t_1)}{M_1 M_2 - N_1 N_2}$ and $s_1^n - s_2^n = A_1 - A_2 = \frac{(a-c_m)(2+3b)(1+k)(t_2-t_1)}{M_1 M_2 - N_1 N_2}$. If $t_1 < t_2$, then $p_1^n > p_2^n$ and $s_1^n > s_2^n$; If $t_1 = t_2$, then $p_1^n = p_2^n$ and $s_1^n = s_2^n$; if $t_1 > t_2$, then $p_1^n < p_2^n$ and $s_1^n < s_2^n$. Similarly, from Table 3, we get the same results in the price and service competition models. Hence, if $t_1 < t_2$, then $p_1^\xi > p_2^\xi$ and $s_1^\xi > s_2^\xi$; if $t_1 = t_2$, then $p_1^\xi = p_2^\xi$ and $s_1^\xi = s_2^\xi$; if $t_1 > t_2$, then $p_1^\xi < p_2^\xi$ and $s_1^\xi < s_2^\xi$, where $\xi \in \{n, s, p, h\}$.